Subcritical Benchmark of the BeRP Ball Reflected by Tungsten

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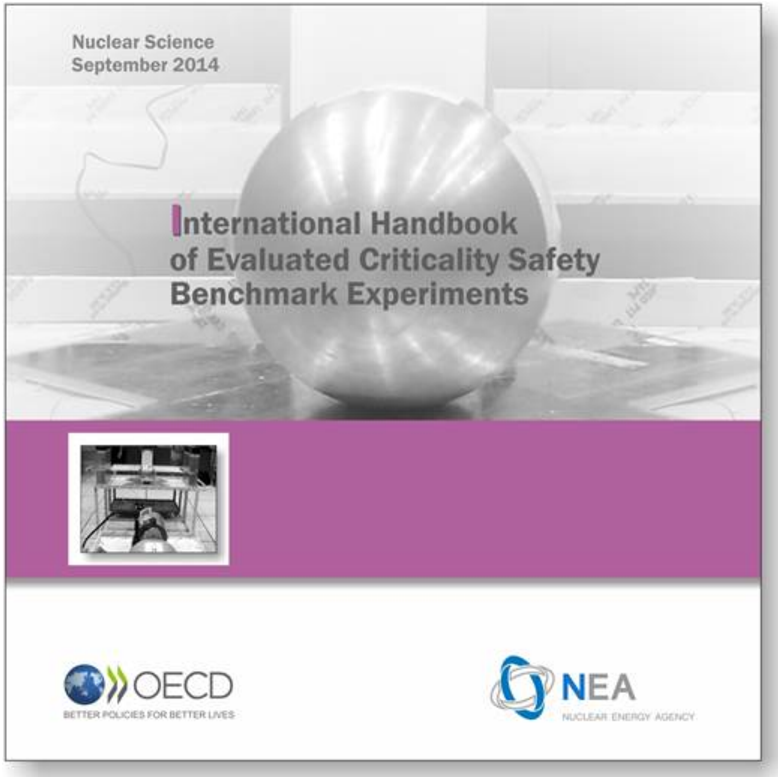
Presented at the 2016 NCSP TPR

LA-UR-16-21654

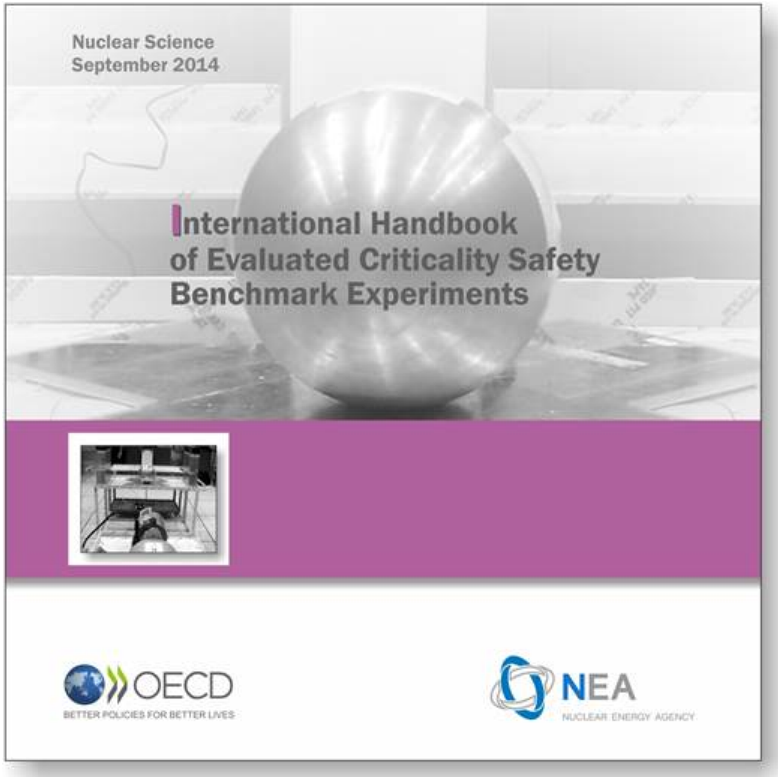
General Overview

- **The BeRP ball reflected by nickel benchmark evaluation was published in the 2014 edition of the ICSBEP handbook.**
- **This benchmark was the first:**
  - Published benchmark evaluation of measurements performed at DAF.
  - Benchmark evaluation using new MCNP capabilities for subcritical systems (the MCNP list-mode patch and MCNP6 list-mode capabilities).
  - Benchmark using the Feynman Variance-to-Mean method.
  - LANL-led subcritical experiment in the ICSBEP handbook.
- **This benchmark was the culmination of the last 5 years of subcritical experiment research funded by the NCSP.**



General Overview

- **The BeRP ball reflected by tungsten benchmark evaluation will be very similar to the nickel evaluation.**
  - Same detectors
  - Same Pu sphere
  - Same experimental setup
  - Same data analysis methods
- **Planning for inclusion in the 2016 edition of the ICSBEP handbook.**
- **Benchmark measurements were performed in September 2012 at the National Criticality Experiments Research Center (NCERC).**
- **This work presents PRELIMINARY measurement and simulation results.**



General Overview

- **Subcritical multiplying systems provide valuable information.**
  - Validation of nuclear data and codes.
  - Uncertainty quantification for various applications.
  - Allows for multiple configurations at various reactivity states for a single experiment.

- **Monte Carlo simulations of an experimental subcritical benchmark:**
  - Help validate improvements in computational tools.
  - Provide better predictability and understanding in the sensitivities and uncertainties associated with subcritical systems.

BeRP Ball

- **α-phase plutonium sphere (93.73 wt.% Pu-239)**
- **4483.884 g, 7.5876 cm diameter**
- **Calculated density 19.604 g/cm³**
- **Encapsulated in SS 304 cladding**
- **Machined in 1980**
- **Previous benchmarks:**
  - Be reflected critical experiment (PU-MET-FAST-038)
  - HEU “reflected” “Rocky Flats Shells” (MIX-MET-FAST-013)
  - CSDNA subcritical noise measurements with polyethylene reflection (SUB-PU-MET-FAST-001)
  - Ni reflected subcritical experiment (FUND-NCERC-PU-HE3-MULT-001)

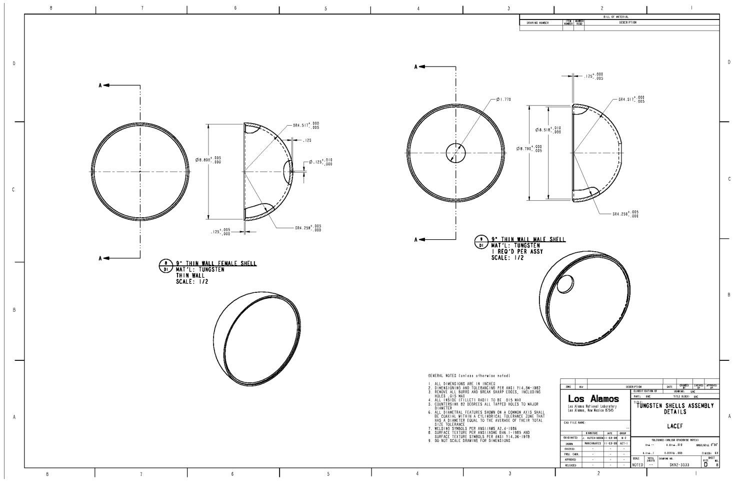
Tungsten shells

- Reactivity range: k_{eff} = 0.78 to k_{eff} = 0.94
- 8 configurations: 0 (bare), 0.5, 1.0, 1.5, 2.0, 2.5, 2.75, 3.0 inch-thick W
- 7 layers, each layer is composed of two hemishells
- Class 4 tungsten: nominally 97 wt.% W (balance mostly Ni and Fe)

Tungsten shells

- **Average density of 18.567 g/cm³**

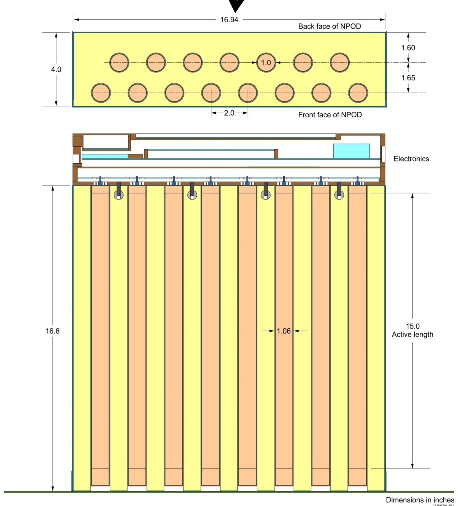
Outermost Nickel Shell Thickness (in.)	ID (in.)	OD (in.)	Measured Mass (g)		Calculated Volume (cm³)	Calculated Density (g/cm³)
	Male + Female Shell	Male + Female Shell	Male Shell	Female Shell	Male + Female Shell	Male + Female Shell
0.5	1.5375	2.0145	2608.3	2614.6	285.42	18.299
1.0	2.0205	2.5145	4786.1	4675.2	510.18	18.545
1.5	2.5205	3.0145	7276.4	6989.8	768.83	18.556
2.0	3.0205	3.5145	10258.5	9879.2	1078.66	18.669
2.5	3.5205	4.0145	13553.7	13253.6	1440.05	18.616
2.75	4.0205	4.2555	7811.1	7886.6	836.53	18.765
3.0	4.2615	4.5145	9382.9	9364.0	1012.55	18.515
Average						18.567

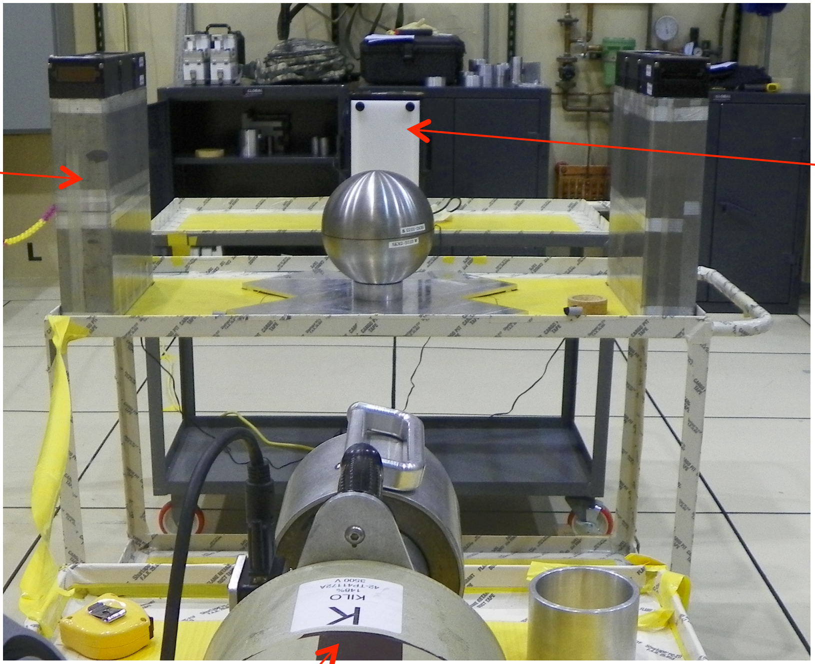


Detector setup

NPOD detectors: 15 He-3 tubes inside polyethylene and wrapped in Cd.

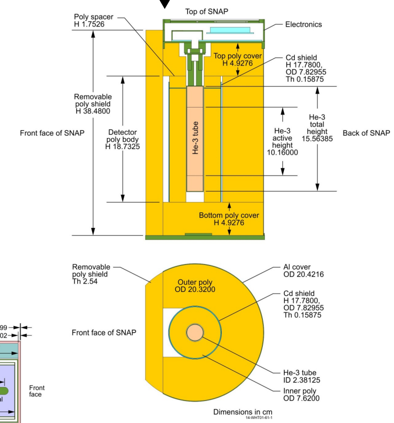
50.0 cm from center of BeRP to Cd face of NPOD.





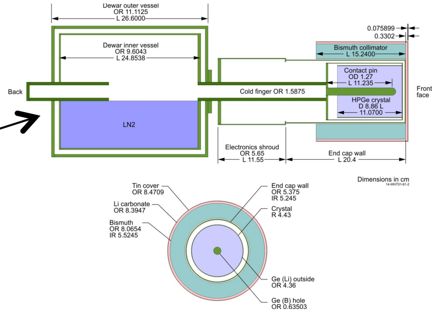
SNAP detector: Single He-3 tube inside polyethylene and Cd. Has a removable 1 inch-thick poly shield.

100.0 cm from center of BeRP to center of He-3 tube.



HPGe detector: LN2 cooled HPGe detector with bismuth collimator.

150.0 cm from center of BeRP to face of detector.



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Benchmark quantities

- Must be deduced from well-known and fieldproven techniques
- Fundamental quantities having nevertheless a practical meaning
- Accessible and reliable uncertainty determination
- Must enable the discrimination without any ambiguity of each studied configuration

Documented in a LANL report and ICNC 2015 paper.

Selected quantities

- Directly deduced from the Feynman histogram:
  - R_1: singles asymptotic counting rate
  - R_2: doubles asymptotic counting rate
- M: neutron multiplication

Beneficial because they are basic quantities (easy to measure). Uncertainties are purely statistical. Unfortunately the values are dependent upon the detector system.

Leakage multiplication beneficial because the value is independent of the detector system used (note that the uncertainty is still dependent upon the detector system). A more advanced parameter that involves additional calculation and assumptions to obtain.

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Selected quantities

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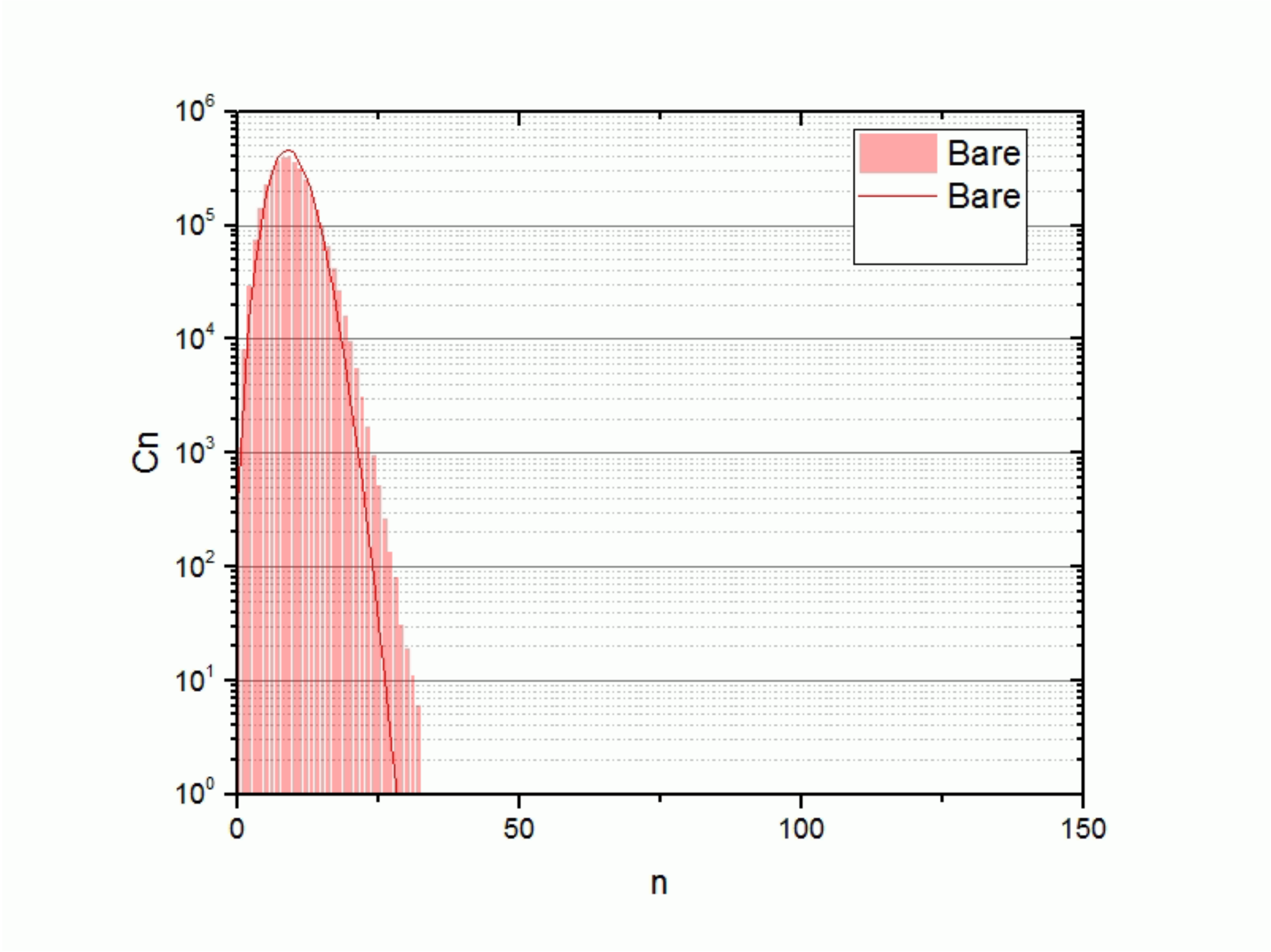
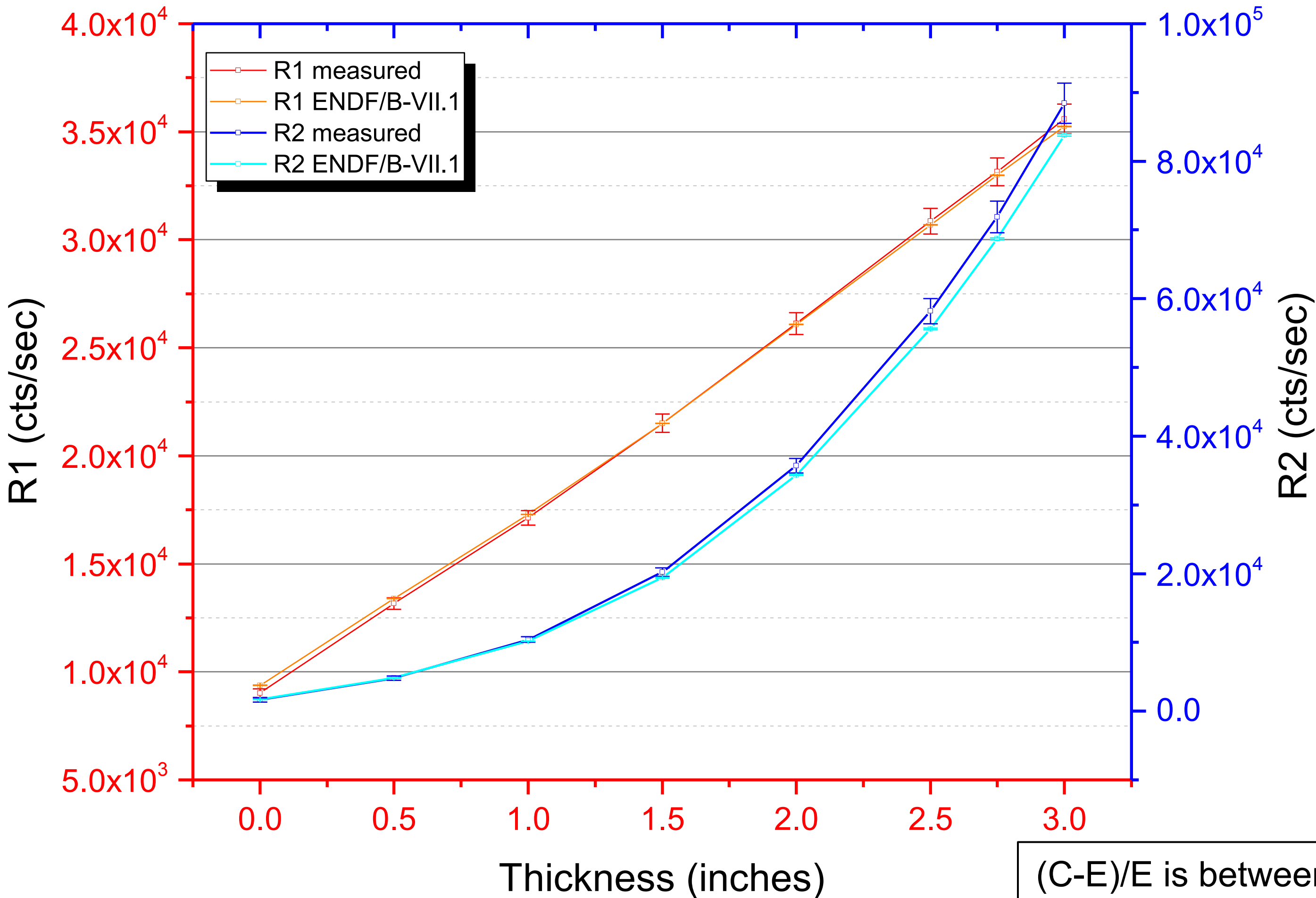
Note that k_{eff} is not a benchmarked quantity in this evaluation. Measured k_{eff} values are, however, given for each of the configurations.

BeRP results: histograms

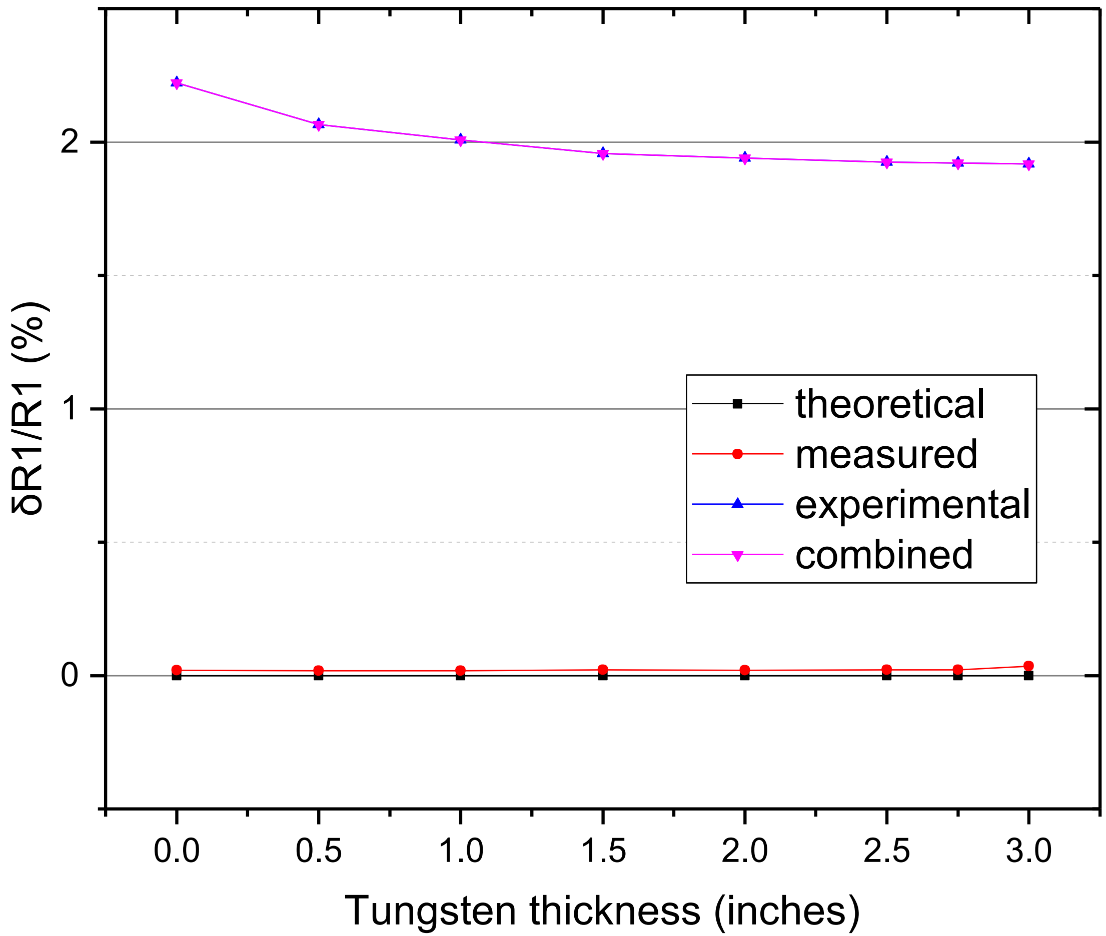


BeRP results: count rates



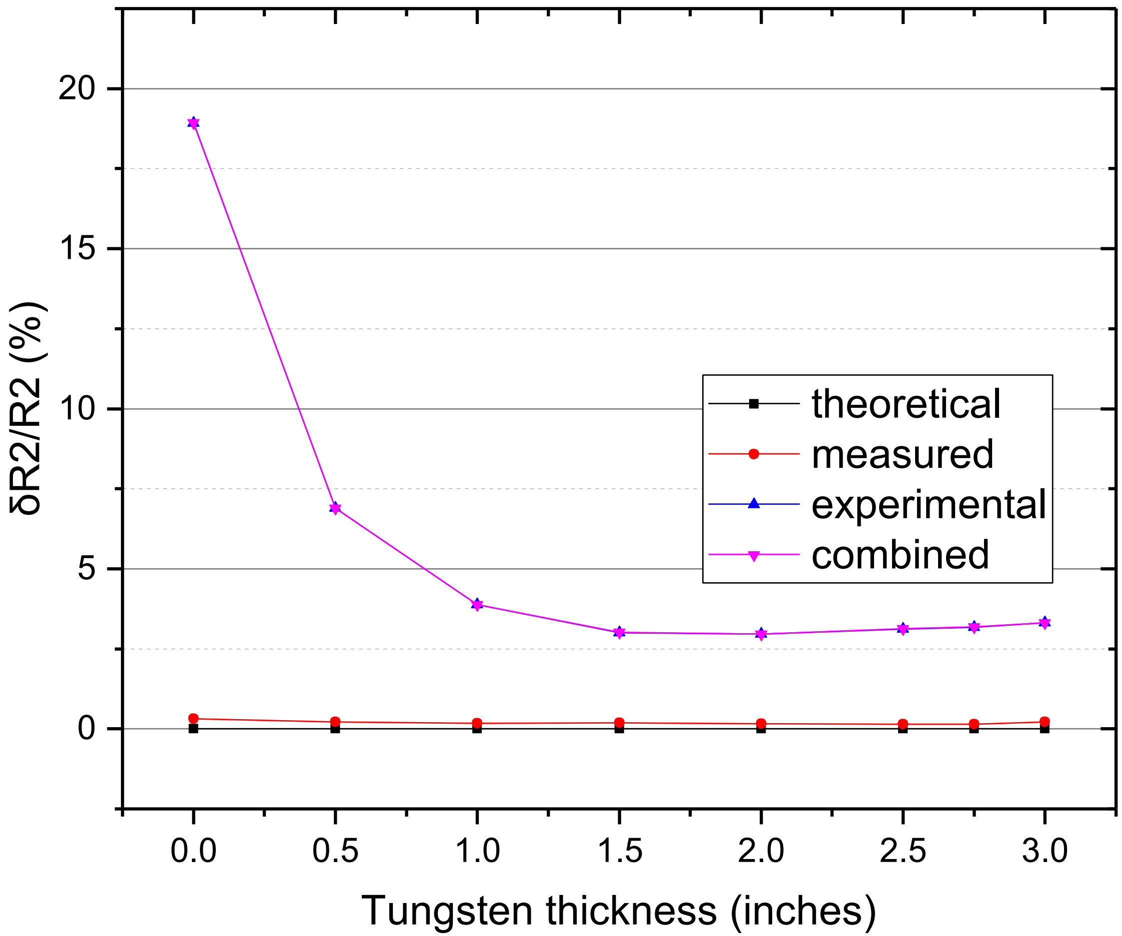
(C-E)/E is between -5% to 5% for all configurations

BeRP results: count rates



Experimental (systematic) uncertainties dominated the total combined uncertainty.

BeRP results: count rates



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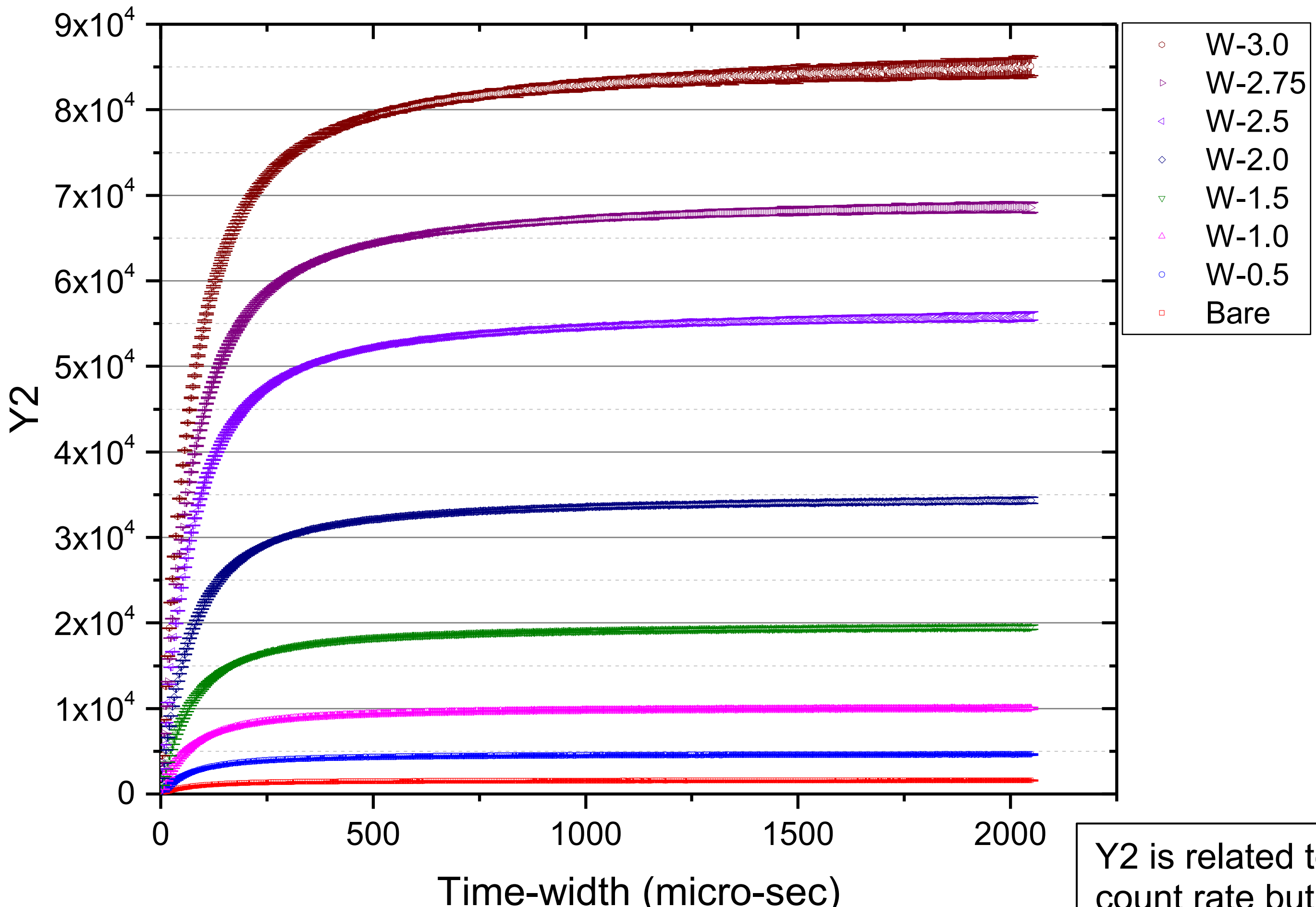
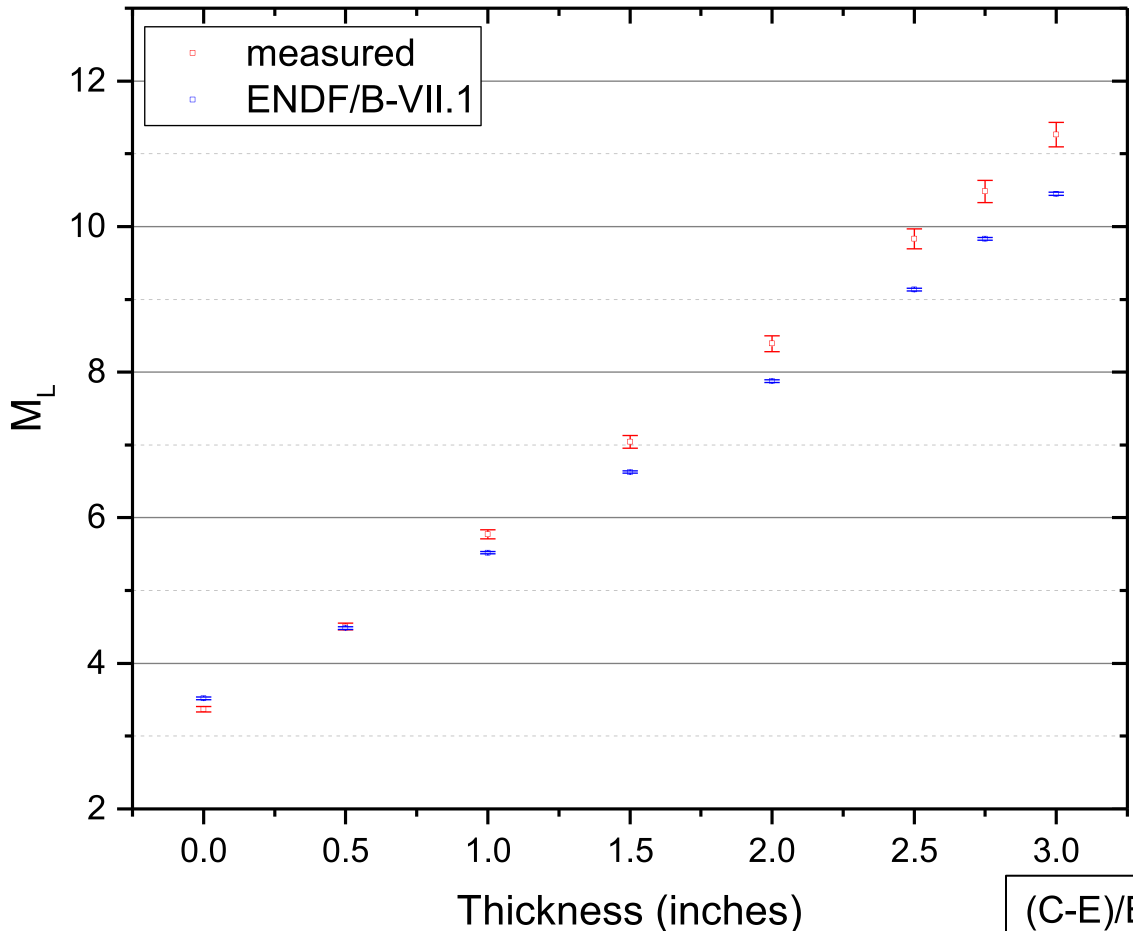


Y2 is related to doubles count rate but does not include detector lifetime

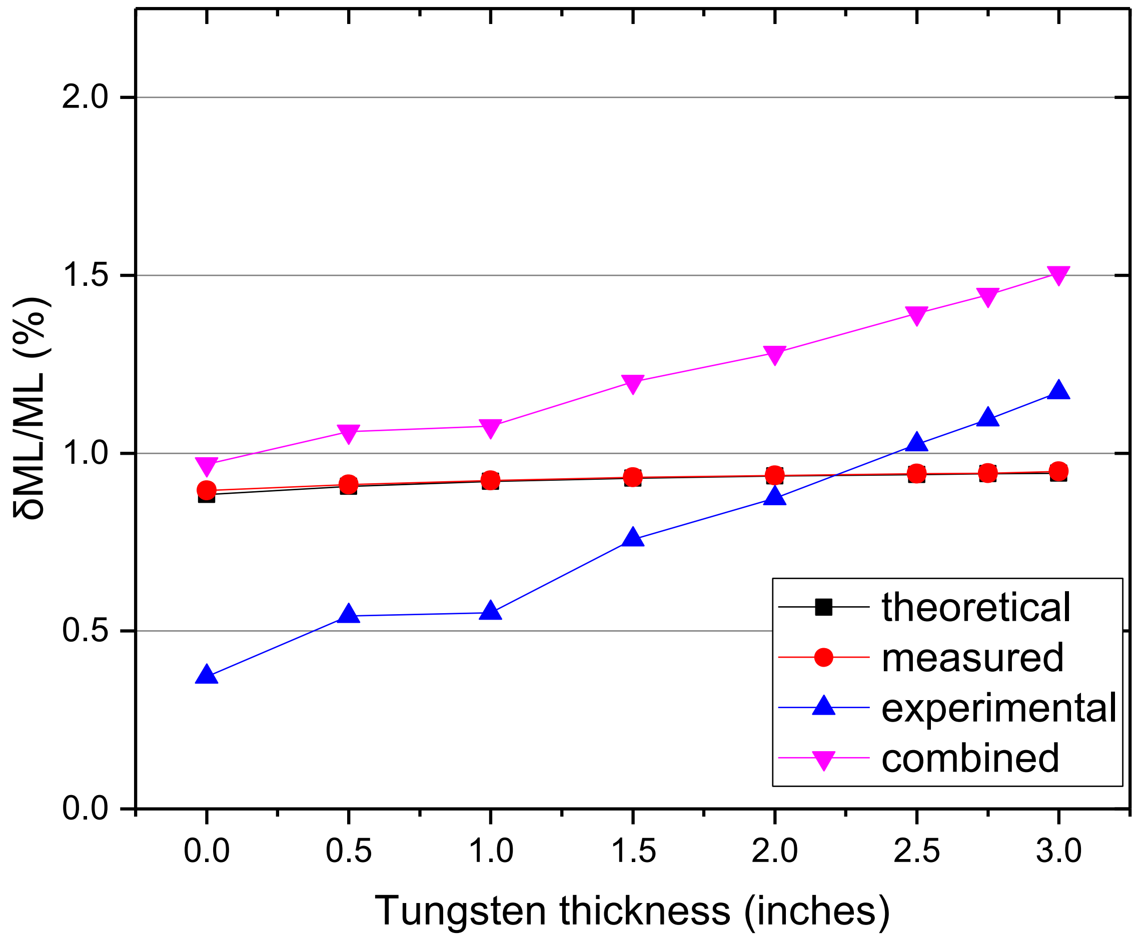
BeRP results: leakage multiplication



For BeRP/Ni, JEFF 3.1 generally agreed better than ENDF/B-VII.1 for all 3 parameters. JEFF 3.1 models have not been run yet for BeRP/W

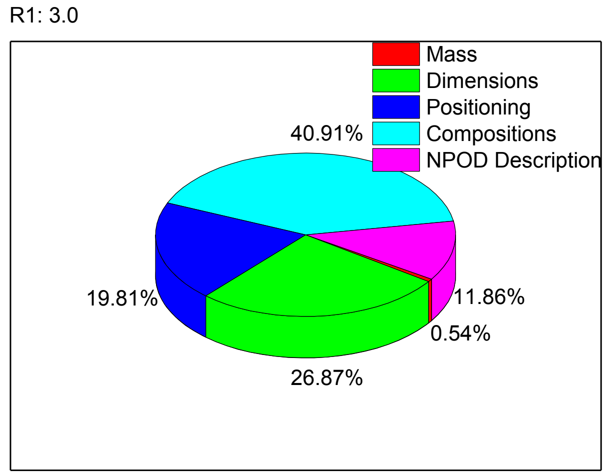
(C-E)/E is between -7% to 5% for all configurations

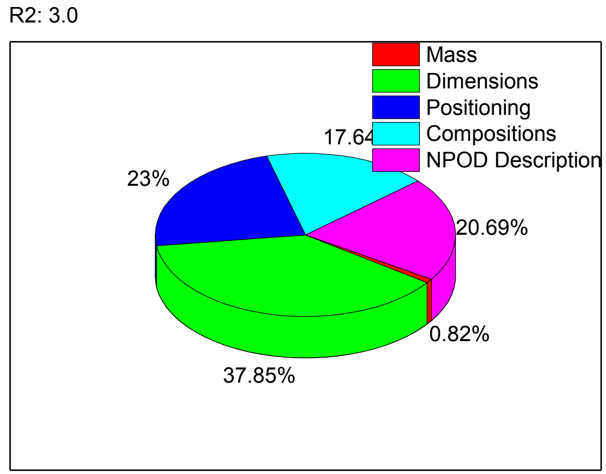
BeRP results: leakage multiplication

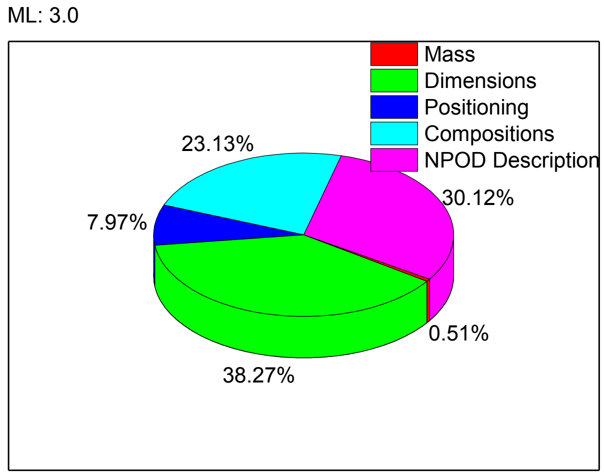


Experimental and measurement uncertainties both contribute significantly to the total combined uncertainty.

BeRP results: experimental uncertainties







Fairly similar to BeRP/Ni results.

Conclusions and future work

- **Eight subcritical configurations were measured with a plutonium sphere reflected by tungsten.**
- **All configurations were analyzed.**
- **ALL measured data will be included in the evaluation.**
  - Raw list-mode neutron data.
  - Processed list-mode neutron data (using multiple binning methods).
  - Raw gamma spectra.

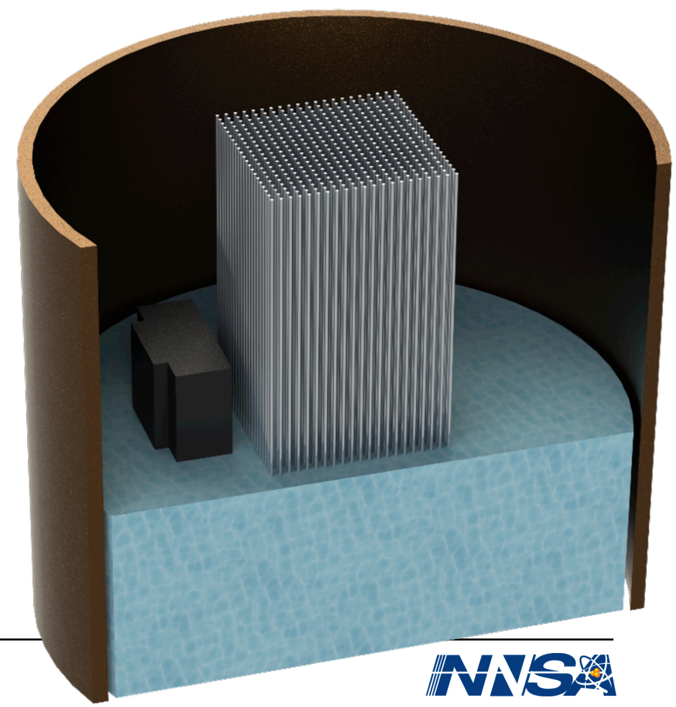
Conclusions and future work

- **Detailed model and simplified models have been created.**
  - Sensitivity analysis (and all other simulations are nearly complete).
- **Draft submitted to external reviewers on Feb 12 2016.**
  - LLNL and IRSN are both providing external reviews of the BeRP/W evaluation.
- **Draft submitted to working group on Mar 02 2016.**
- **Will be presented at ICSBEP in April 2016.**
- **Included in the 2016 edition.**

	Number of files	Simulation time (hours)
Detailed	8	39
Simplified	8	33
Sensitivities	130	540
Bias	5	27
Cf-252	8	27
Additional	12	14
Total	171	680

Conclusions and future work

- **Many IERs exist related to subcritical measurements. Two important ones for LANL include:**
  - 1. IER-~~111~~422: Subcritical Copper-Reflected α-phase Plutonium (SCRαP) Integral Experiment.
    - Currently in CED-2.
    - Joint experiment with US, IRSN, and AWE.
  - 2. IER-178: Measurements on the RPI Reactor Critical Facility (RCF).
    - Will build upon recent measurements on Caliban, Godiva-IV, Planet (Lucite class foils experiment), and Flat-Top (with HEU core).
    - Will be the only measured list-mode data set on a thermal system in which reactivity states from control rod worth curves can be compared.
    - Measurements to take place this summer.



Acknowledgements

- **This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.**
- **This benchmark was a very large effort and would not have been possible without help from the following:**
  - Members from LLNL, ORNL, and INL contributed both at ICSBEP and on the Critical Experiments Design Team (C_EdT).
  - NEN-6 and NSTec helped with support at the DAF to accomplish these measurements.
  - Benoit Richard and Theresa Cutler should be recognized for the huge amount of effort they put into this work.
  - We would also like to thank Mark Smith-Nelson for participation in the measurement effort and C.J. Solomon for advancing the simulation capabilities required for this work.
  - We would like to thank Gregory Keefer and Sean Walston from LLNL, Gregory Caplin and Wilfried Monange from IRSN, and John Bess from INL. Their thorough reviews greatly improved the quality of the evaluation.
  - Last, we would like to thank Bill Myers, Dave Hayes, Avneet Sood, and Bob Margevicius for their continued support of this work.